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EXPERIMENTAL STUDY ON HUMAN EXPOSURE TO OCCUPANT GENERATED POLLUTANTS IN ROOMS WITH DUCTLESS PERSONALIZED VENTILATION

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SUMMARY

The performance of “ductless” personalized ventilation in conjunction with displacement ventilation with regard to exposure to different body bioeffluents was studied. Experiments were performed in a full-scale room furnished as a double office. Room air temperature was kept at 26 ^{o}C. Two breathing thermal manikins were used to simulate occupants. Tracer gases were used to simulate human bioeffluents (feet, groins, armpits and exhaled air) released from one manikin, simulating polluting occupant. The second manikin simulated exposed occupant. Different combinations of supply flow rates and operation modes for the ductless personalized and displacement ventilation were tested. The location of the bioeffluent source affected the spread of body bioeffluents in the space. The ductless personalized ventilation provided cleaner air to both occupants than displacement ventilation alone. Occupants using the ”ductless” system will perceive the supplied air quality as superior compared to displacement ventilation alone.

INTRODUCTION

Preferences regarding the indoor environment differ between individuals to a large extent. Even for the same person the preferred environment may change from day to day as well as during the same day. Instead of providing a uniform indoor environment and ventilate unoccupied zones in the room (waste of energy) we can provide the air where, when and as much as needed delegating individual control to every person (Melikov 2011). Personalized ventilation (PV) is a type of localized individually controlled ventilation that provides the clean and cool air close to each occupant, i.e. within the breathing zone (Melikov 2004).

Recently, a novel air distribution system, named “ductless” personalized ventilation (DPV) in conjunction with displacement ventilation was introduced (Halvonova and Melikov 2010). The outdoor treated air supplied to the room by displacement ventilation spreads over the floor, and is sucked by a fan mounted on the workstation, and supplied from the desk mounted PV air terminal device within the breathing zone of the occupant. The main idea behind the DPV is to utilise the clean air that is spread over the floor more efficiently.

The performance of DPV with regard to airborne pollution from exhaled air was studied in previous study (Halvonová and Melikov, 2010). Study on air quality performance of DPV when the source of pollution is body generated bioeffluents is required, especially when the pollutants are generated from the feet, as feet are closest to the DPV intake and thus may affect the quality of air supplied to the occupant. The purpose of the present study was to identify the performance of DPV in conjunction with DV with regard to exposure to bioeffluent contaminants in an office room with two occupants under summer conditions.

METHODOLOGIES

Experimental Layout

The measurements were performed in a full-scale room with dimensions 3.6 × 4.8 × 2.6 m^3 (L x W x H), built in a laboratory hall, 0.7 m above the floor. The laboratory hall has a separate ventilation system and temperature control. In order to reduce the heat exchange the ambient temperature in the hall was kept the same as that in the test room. The room was arranged as an office with two identical workstations. Each workstation consisted of a desk with an installed DPV system, a personal laptop, and a desk lamp (22 W/m^2), Figure 1. Two breathing thermal manikins were placed behind each workstation. The two manikins had realistic body shape and were used to simulate the heat generated by and the natural convection flow around a seated occupant at light sedentary activity. Both thermal manikins were wearing typical summer clothes (0.59 clo), including the upholstered office chair. The manikin simulating a polluting occupant was breathing via a set of artificial lungs (Melikov and Kaczmarczyk 2007): 2.5 sec inhalation, 2.5 sec exhalation and 1 sec break at a tidal flow rate of 6 L/min, Hyldgaard (1994). The manikin was inhaling through the nose and exhaling through the mouth.

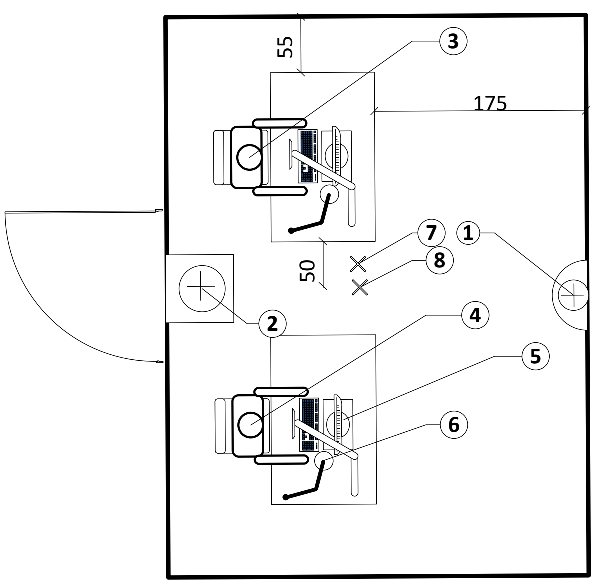

Figure 1. Set –up of the test room: (1) displacement diffuser, (2) exhaust unit, (3) polluting manikin, (4) exposed manikin, (5) laptop, (6) desk lamp, (7),(8) measuring locations,

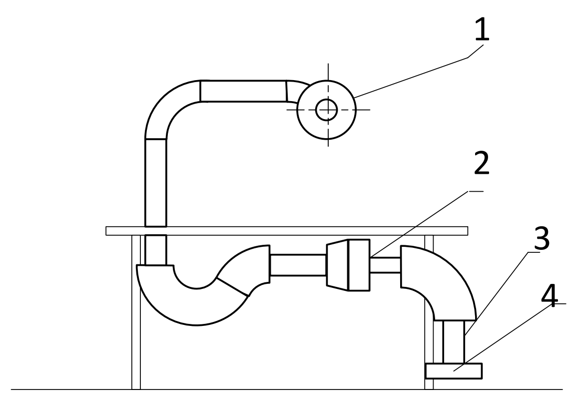

Figure 2. DPV: (1) RMP, (2) installed fan, (3) short duct system, (4) intake of DPV

Ventilation System

Displacement ventilation (DV) was used as a total-volume ventilation principle in the test room. The fresh air was supplied through a semi-circular wall diffuser, Figure 1 position 1. The unit was fitted with nozzles, supplying air uniformly in a half circle. The room air was exhausted via a rectangular perforated air terminal device installed in the ceiling (Figure 1, position 2).

On each workstation a DPV system was installed consisting of a circular air terminal device (ATD) named round movable panel, RMP (Bolashikov et al. 2003), and a duct fan in a short non-insulated duct system (Figure 2). The rectangular-shaped intake of the DPV system (0.20 m x 0.20 m x 0.06 m (L x W x H), Fig. 2) was set 0.05 m above the floor. The RMP was attached to a movable arm allowing free positioning of the ATD. In this study the RMPs were positioned frontally (0.4 m from the face) and slightly from above, which was the positioning most often preferred by people (Kaczmarczyk et al. 2004, 2006).

Contaminant Sources

The "breathing" thermal manikin was used to mimic a polluting occupant. It is referred in the text as polluting manikin (PM). The second thermal manikin was used to mimic exposed person and was not breathing; exposed manikin (EM). Four different contaminants were simulated: bioeffluents from feet (smelly feet) simulated with CO_2, airborne cross infection via exhaled pathogen laden air (contaminated exhaled air) simulated with R 134a, bioeffluents from armpits (smelly armpits) simulated with R 134a and bioeffluents from groins (smelly groins) simulated with SF6. The tracer gases were dosed at constant rate at each location described. Because exhaled air and bioeffluents from armpits used the same tracer gas, namely R 134a, the measurements were performed two times and each time the position of the dosing location was changed. In the first case it was in the artificial lungs and in the second case it was moved under the armpits.

Experimental Conditions

The flow rate and temperature of the air supplied by the DV was kept constant, respectively 90 L/s at 23 °C. The room air temperature at point 7, Figure 1, at the height of 1.1 m above the floor was kept constant at 26 ^{o}C. Only two DPV flow rates were studied during the measurements: 6 and 10 L/s. In practice, more flow rates may be selected by the occupants. For each contaminant simulated, there were 7 cases that cover four different combinations of each DPV airflow rate, which are: no DPVs ON (DV alone at 90 L/s supply), and six cases of combinations of two DPV supply flows (6 and 10 L/s) in conjunction with DV at 90 L/s, namely: 1) DPV of 10 L/s at both workstations, 2) DPV of 10 L/s at PM workstation only, 3) DPV of 10 L/s at EM workstation only, 4) DPV of 6 L/s at both workstations, 5) DPV of 6 L/s at PM only and 6) DPV of 6 L/s at EM only.

Measured Quantities and Measuring Equipment

The tracer gas concentration was measured with a multi-gas analyzer based on the photo-acoustic infrared detection method. In the experiment, tracer gas concentration at eight different heights at location 8 (Figure 1) was measured. The eight heights were 0.05, 0.1, 0.2, 06, 1.1, 1.4, 1.7, and

2.2 m. However these results are not reported in the present paper. Concentration in supply and exhaust air was measured as well. Measurements of the concentration of tracer gases in inhaled air by exposed and polluting manikin were performed as well. The concentration of R 134a when dosed in the lungs of the polluting manikin was measured only at the mouth of the exposed manikin.

Temperature of air inhaled by the exposed manikin was also measured via thermistor sensor with accuracy of ± 0.2 K. It was measured in the mouth cavity of the exposed manikin.

Indicators for Assessment

One of the most important tasks in this study was to compare the contaminant removal capacity difference when DV was working alone and when DV was operated in conjunction with DPV. Thus tracer gas concentration was normalized to the DV reference case according to equation (1):

$$\text{Normalized Value} = \frac{C_{i\_DPV} - C_{s2}}{C_{i\_DV} - C_{s1}} \qquad \text{Eq. (1)}$$

, where C_{i_DPV} is the concentration of tracer gas (CO_2, SF_6 or R134a) inhaled by manikin when DPV was operated in conjunction with DV, C_{i_DV} is the tracer gas concentration measured in the breathing zone of the manikins when DV was working alone, and C_{s1}, C_{s2} are the tracer gas concentrations in the air supplied by DV and by DPV respectively. If the Normalized Value 2 was bigger than 1 then the performance of DPV in conjunction with DV was worse compared to DV alone.

RESULTS AND DISCUSSION

Contaminant Concentration in the Inhaled Air of Exposed and Polluting Manikins

The normalized concentration for the simulated bioeffluents (from feet, groins, armpits and exhaled air) for the tested combinations of personalized flows (6 or 10 L/s) and use of DPV with respect to the bioeffluent concentration when displacement ventilation at 90 L/s was working alone is shown in Figure 3. Compared to DV alone, the use of DVP at the EM workstation decreased the bioeffluents from feet in the air inhaled by the exposed manikin regardless of the DPV supply flow rate, Figure 3a. Even when the DPV of the polluting manikin was only working the pollution from the feet, transported upwards by the free convection of the PM, was “blown” away from the occupied zone. This resulted in better performance of the DPV unit compared to DV alone. The air quality of the polluting occupant with respect to bioeffluent pollution from feet was sensitive to whether or not the polluting person was using the DPV or not, Figure 3b. When the DPV was not operated the free convection around the body of the polluting occupant moved the feet generated bioeffluents upwards into the mouth. This resulted in worse air quality for the polluting person compared to the case when displacement ventilation was operated alone.

For the groins, however, almost no improvement in the quality of the air inhaled by the exposed occupant was found when the DPV at the EM workstation was operated, compared to DV alone, Figure 3a. The normalized concentrations were above 1 only in the cases when the DPV was used at the EM workstation or at both workstations for the high PV flow of 10 L/s, Figure 3a. The contaminant concentrations from groins measured in the remaining cases with DPV for the exposed person were lower or equal to the concentration measured with DV alone, Figure 3a. The higher supply DPV rate of 10 L/s from the EM workstation generates mixing in the occupied zone that stirred the rising convection flow of the polluting manikin and mixed the groins' bioeffluents with the surrounding air, compared to the case of DPV at 6 L/s. This resulted in the high pollutant concentration from groins for the exposed occupant. However this needs to be carefully further investigated. For the polluting manikin the use of DPV under all studied cases resulted in lower concentration of groins' bioeffluents in the inhaled air compared to DV alone.

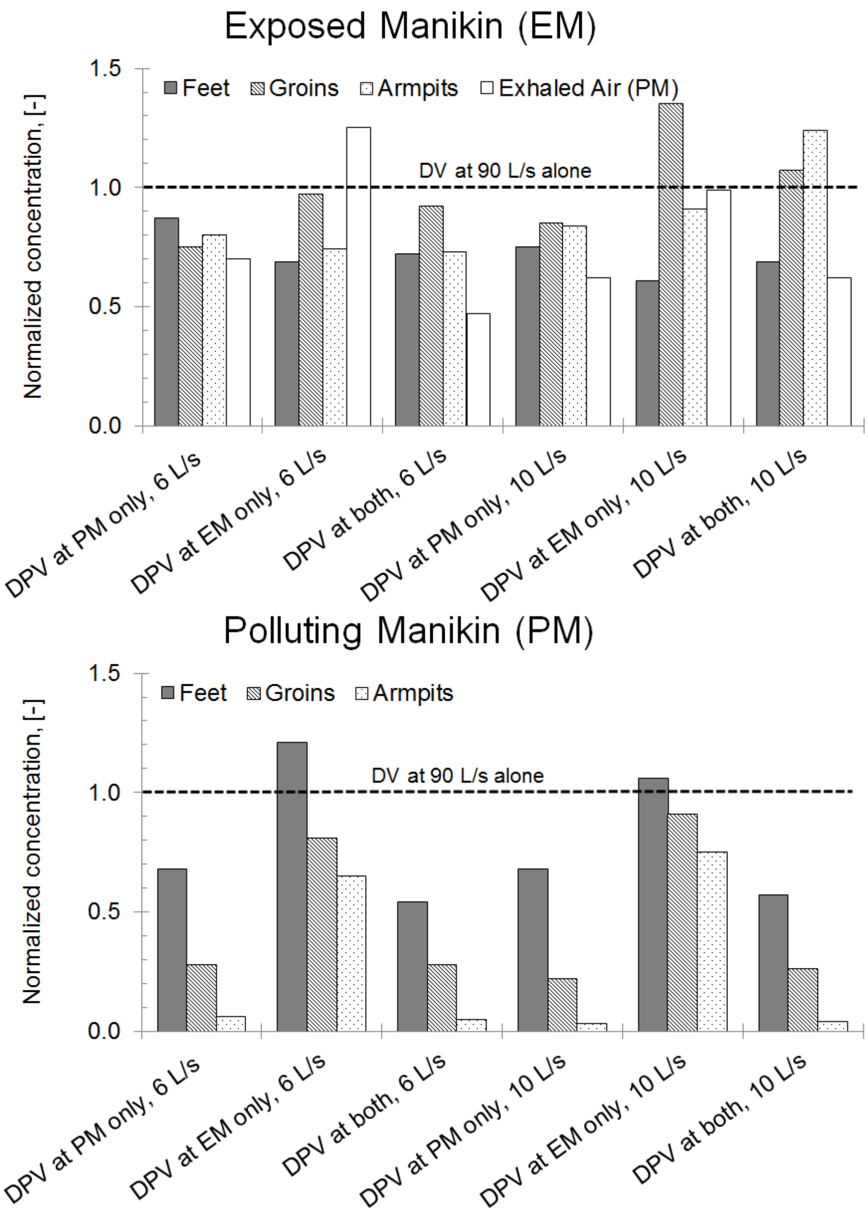

Figure 3. Normalized Value for four contaminants in the air inhaled by a) the EM (exposed manikin) and b) the PM (polluting manikin) for different DPV operation cases

Using DPV in conjunction with DV provides better air quality with regards to bioeffluents from armpits to both occupants (exposed and polluting) compared to DV operated alone, Figure 3. Only when the DPV provided 10 L/s at both workstations did the exposed manikin inhale more polluted air from armpits' bioeffluents compared to when DV was operated alone, Figure 3a. The higher flow rates of 10 L/s, generated more mixing in the room and lead to decrease in the stratification height of the displacement ventilation (not reported here). The exposure to bioeffluents from armpits for the polluting manikin was reduced even in the case when only the exposed manikin was using the DPV system compared to DV alone, Figure 3b. One possible explanation can be that the air provided in the upper half of the room by the DPV at the EM workstation diluted the pollutant concentration in the occupied zone at breathing level. However this hypothesis needs to be further studied.

As already mentioned the exposure to the exhaled air from the polluting manikin is reported only for the exposed manikin. With regard to contaminated exhaled air, the use of DPV was effective regardless of the flow rate of DPV when it was used at either PM workstation, or at both workstations, Figure 3b. It was expected that the use of the DPV at the EM workstation would improve the air quality of the exposed manikin with regard to the exhaled contaminants from the PM. However, the results reveal that the use of DPV at EM workstation only increased the concentration of exhaled polluted air inhaled by the EM when DPV was operated at 6 L/s and remained nearly 1 (as DV case alone) when the EM DPV was operated at 10 L/s. The use of the DPV at either or both workstations destroyed the displacement pattern in the room. Therefore the clean air mixed more with the exhaled air. So when the DPV at the workstation of the EM was working it sucked mixed polluted air from the lower level of the room and blew it directly into the breathing zone. When the DPV at PM workstation was operated or when both DPVs were working the exhaled air was "blown" away by the DPV of the PM and did not mix that much in the occupied zone. However this needs to be further studied.

Inhaled Air Temperature

The highest temperature of inhaled air was measured in case when the DPV at EM workstation was not operated or when the DV worked alone, Figure 4. When the DPV at the EM workstation was turned on, the air supplied by DPV to the breathing zone was able to decrease the temperature of the inhaled air, by nearly 3 K, Figure 4. As expected, the cool air supplied by the DPV system at the workstation of the polluting manikin did not affect the temperature of the air inhaled by the exposed manikin, i.e. that the use of the DPV by one manikin does not affect the inhaled air temperature of the other manikin.

Under the same level of contaminant concentration in the background, the perceived air quality is supposed to be better, if the inhaled air temperature is in the lower range of room air temperatures recommended in EN 15251 (2007), Fang et al. 1998. Combined with elevated velocities at the face and cleaner air for breathing, the occupant using DPV will always end sensing the air delivered by the personalized unit as of "better" air quality compared to DV alone and will report less SBS symptoms (Melikov and Kaczmarczyk 2012).

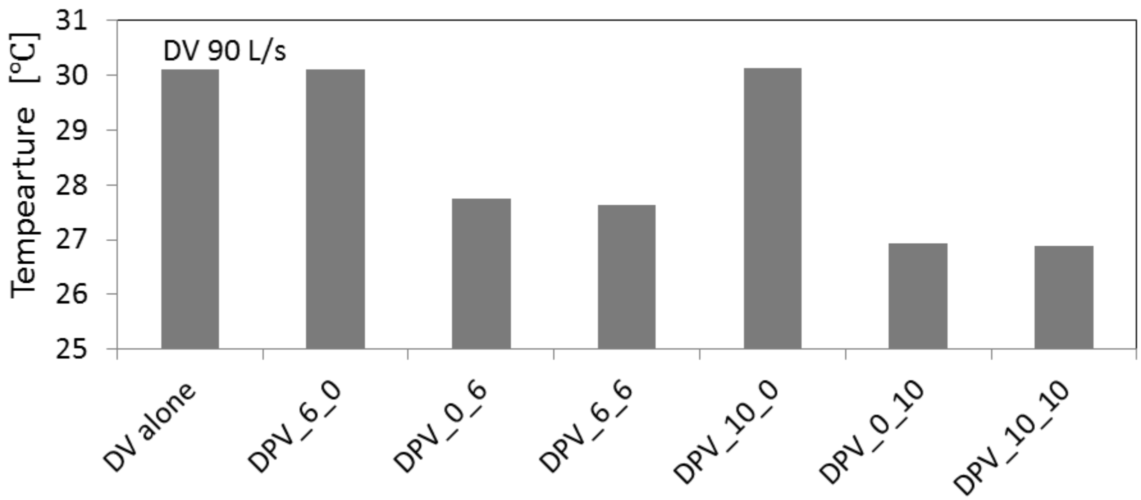

Figure 4. Inhaled air temperature of the EM in different cases with different modes of DPV operation, at DV supply flow rate of 90 L/s.

CONCLUSIONS

The air quality performance of ductless personalized ventilation was studied with respect to body generated bioeffluents from feet, groins, armpits and exhaled air (bad breath or pathogen laden air) in a double office room. The following conclusions were made:

- The location of bioeffluent pollution sources has impact on the performance of DV used alone and also on the performance of DPV in conjunction with DV. The polluting person generating pollution from feet, groins, armpit and exhaled air was found to be more exposed to pollution from feet and groins than pollution from armpits. The exposed person was found to be more exposed to bioefflents from groins.
- The quality of air inhaled by the occupants depends on the combination of the use of DPV at the two workstations and the DPV supply flow rate. For the exposed person the lower supply flow rate of 6 L/s of the DPV resulted in better air quality. The higher supply flow of 10 L/s for the DPV generated better air quality for the polluting occupant.
- The use of DPVs, will always be able to protect the occupants from bioeffluents' pollution better, or at least will provide air as clean as DV alone.
- The use of the DPV system is able to transport cooler air to the inhalation compared to displacement ventilation alone. The decreased inhaled air temperature, together with the cleanness of the personalized air supplied at elevated facial velocity, will ensure in practice much better perceived air quality and will decrease SBS symptoms compared to DV alone.

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